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CAPACITIVE CREEP STRAIN MEASUREMENTS FOR PREDICTIVE LIFE DETERMINATIONS

by
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Catastrophic ruptures of pipe sections in four hot reheat piping systems, as well as numerous steam leaks in main steam and hot reheat piping, boiler headers, and turbine shells have drawn increasing recognition by utilities that pipes, boiler headers, turbines, and other components are subject to gradual deterioration during prolonged service at elevated temperatures. The rate of deterioration tends to accelerate with time and increases with temperature.

The deterioration is often associated with creep representing the gradual elongation, swelling, or expansion of the alloy steel materials conveying superheated steam at elevated temperatures.

Since metals have a limited creep life, the determination of the amount of creep that has occurred in a pipe or header may determine the remaining life of the component.

Since creep relates to time in operation at elevated temperature, as well as localized stresses, the amount of creep (or decrease of remaining life) may vary significantly along the length of a main steam or hot reheat piping system, a superheater outlet header, or a turbine connection.

In some piping systems, rupture at the highly stressed location may occur after a period of less than 100,000 hours of service, as applied to four catastrophic ruptures in hot reheat piping systems. However, at other locations in the same systems, the pipe may have a life of 400,000 hours or more.

Pipe ruptures or even failures can result in extremely costly interruptions of operations. In some of the larger power plants, unscheduled outages caused by thru-wall cracking across a pipe or header may cost as much as $10,000 to $250,000 per day or more. The determination of creep at locations of high stress to predict the remaining life of piping, headers, turbines or other components thus can provide major cost savings to utilities, assist in long-range planning of component replacements, as well as ensure the safe operation of the high temperature (high energy) piping systems or components.

A very reliable method for the continued determination and monitoring of creep (or life reduction) in piping, boiler components, and high pressure turbines involves capacitive creep strain measurement.

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By utilizing the capacitive strain gages at predetermined high stress locations, the creep of the material at the elevated temperature can be determined and monitored accurately. Fig. 1 shows the creep measured at three locations of a pipe bend in a main steam piping system at locations at the outer arc and the neutral axis. Significantly greater creep occurred at the outer arc of the pipe bend.

Fig. 2 details the temperature of the pipe as recorded at the same time the creep strain measurements were taken.

It should be noted that the creep strain gages were attached to the pipe bend when the piping system had been in service for a period of 177,000 hours. The measurements taken thus represent an additional period of approximately 9,500 hours.

Similar creep strain determinations were recorded on a pipe in another main steam piping system. The creep strain measurements, as well as the associated temperature chart, are provided in Figs. 3 and 4, respectively. The capacitive strain gages were attached after the 2-1/4 Cr - 1 Mo low-alloy steel main steam pipe had been in service for a period of 195,000 hours. The subsequent strain measurement involved a period of almost 20,000 additional hours.

The creep strain measurements are significantly more accurate in determining creep deterioration of pipe, as is illustrated in the sketches provided in Figs. 5 and 6 showing how creep tends to be most severe along the outer surface along the outer arc of the pipe bend. However, at the neutral axis, creep, as evidenced by void formation, developed along the inside surface without significant evidence of creep void formation or fissuring along and below the outside surface. This may explain why in some piping, the cracking has tended to progress from the inside surface towards the outside surface, whereas in other piping, cracking progressed from the outside surface towards the inside surface.

Before selecting areas for creep strain measurements with capacitive strain gages it is desirable to perform a system walkdown and a stress analysis of the piping system or component. At locations of high stress, as well as at locations where the system walkdown has shown excessive distortion, as evidenced by pipe supports topping out or bottoming out, such locations are likely to represent preferred areas for the attachment of the capacitive strain gages. At other locations where traditionally cracking seems to occur representing branch locations, involving wye or tee fittings, nozzle joints, or superheater outlet and turbine inlet connections, high stresses often exist which are more likely to result in crack initiation and thru-wall crack progression. Even at the locations of the girth welds involved stresses will vary around the pipe circumference.

After the stress analysis and piping system walkdowns, and the selection of preferential locations for consideration of the attachments of capacitive strain gages, the surface areas should be examined by replication.

In older piping systems that have been in operation for periods of 50,000 hours or more, it is also considered desirable that actual metal samples be removed for the performance of creep or stress rupture testing. Fig. 7 illustrates a location of a girth weld where creep test samples were removed from the base metal, the heat-affected zone and the weld metal. The locations of test samples removed from a seam weld in a hot reheat pipe are shown in Fig. 8. The test specimens were then evaluated to determine the extent of the prior creep that occurred at the selected locations. This was accomplished by the performance of actual accelerated creep or stress rupture tests conducted for periods of 1,000 to 5,000 hours. Microstructures were also examined for evidence of surface or sub-surface void formation and void linkage, as illustrated in Fig. 9. These results thus represent a baseline establishing the prior deterioration (creep damage) and serving as starting point for the continued monitoring of creep deterioration utilizing capacitive strain gages.

On superheater outlet headers, metal samples for actual creep testing may be removed with weld prober saws or by cutting plug samples from the header, Fig. 10. The results provided a baseline evaluation for the effects of over 200,000 hours of prior operation on the creep properties of the 2-1/4 Cr - 1 Mo low-alloy steel material.

The locations for the actual high temperature creep measurements are then selected and the pipe surface is prepared for the attachment of the capacitive strain gages. Figs. 11 and 12 illustrate typical installations of capacitive strain gages. Prior to the replacement of the insulation, protective covers are spot welded to the pipe surface to insure that the capacitive strain gages remain functional for periods of many years and thus do not require repair or replacement during normal plant operations.

Since measurement of the pipe temperature in conjunction with the creep strain measurement is important, thermocouples are also spot welded to the pipe surface at the locations of the capacitive strain gages.

Baseline and calibration readings are then taken of the capacitive strain gages while the pipe is cold and before the insulation is re-applied, Fig. 13. The insulation is then re-applied and the piping systems are returned to service.

During service, creep strain readings are taken with a portable measuring instrument which is connected to the terminal boxes attached either to the pipe surface, to the building wall, Fig. 14, or to special brackets, Fig. 15.

Capacitive strain gages have been installed on main steam and hot reheat piping, on superheater and reheat outlet headers, at some locations of superheater tubing where unusually high failure rates have been experienced, and on the high-temperature sections of turbine shells subject to cracking. In some instances, where weld repairs have been made of cracked turbine casings, these gages have also been attached to monitor the continued satisfactory operation of the turbine shells.

Conclusions

Capacitive creep strain measurement provides an accurate predictive method for estimating the residual life of high-temperature piping, headers, turbines, and other components. These measurements are particularly advantageous to components that have been subject to 100,000 or more hours of prior operations, where the prior creep damage was slight involving void formation. Even where initial void formation is discovered, the piping or component, if properly monitored, may provide another 150,000 to 250,000 hours of satisfactory and safe service.

The actual measurements, in conjunction with the other evaluation techniques referenced above, thus provide a significant improvement of previous methods applied to the evaluation of creep damage and the determination of the remaining predictive life of the high-temperature systems and components in operating power plants.

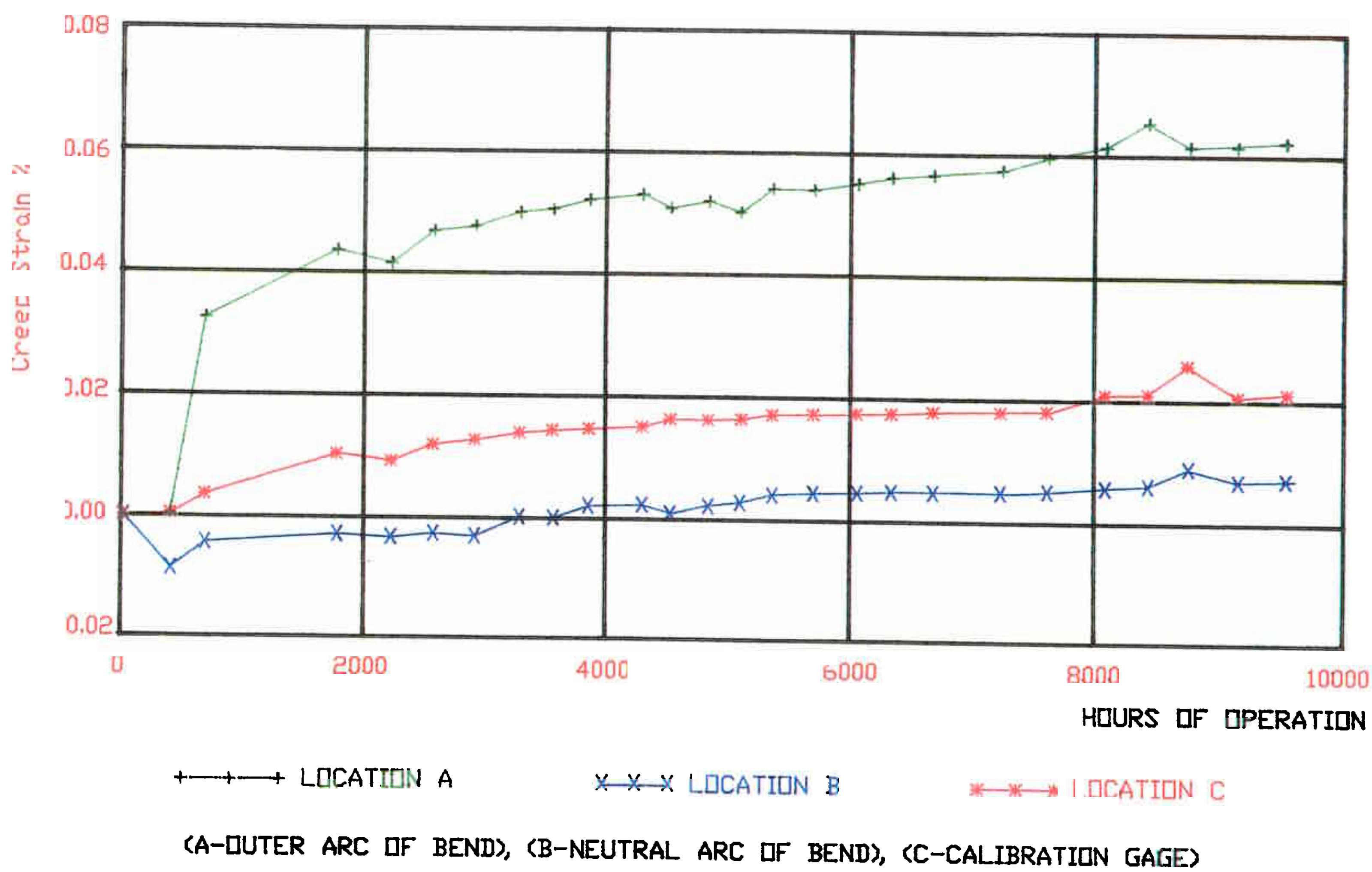

FIG 1. CREEP STRAIN MEASUREMENTS OF PIPE BEND IN MAIN STEAM PIPING SYSTEM INVOLVING 2 1/4Cr - 1Mo LOW ALLOY STEEL.

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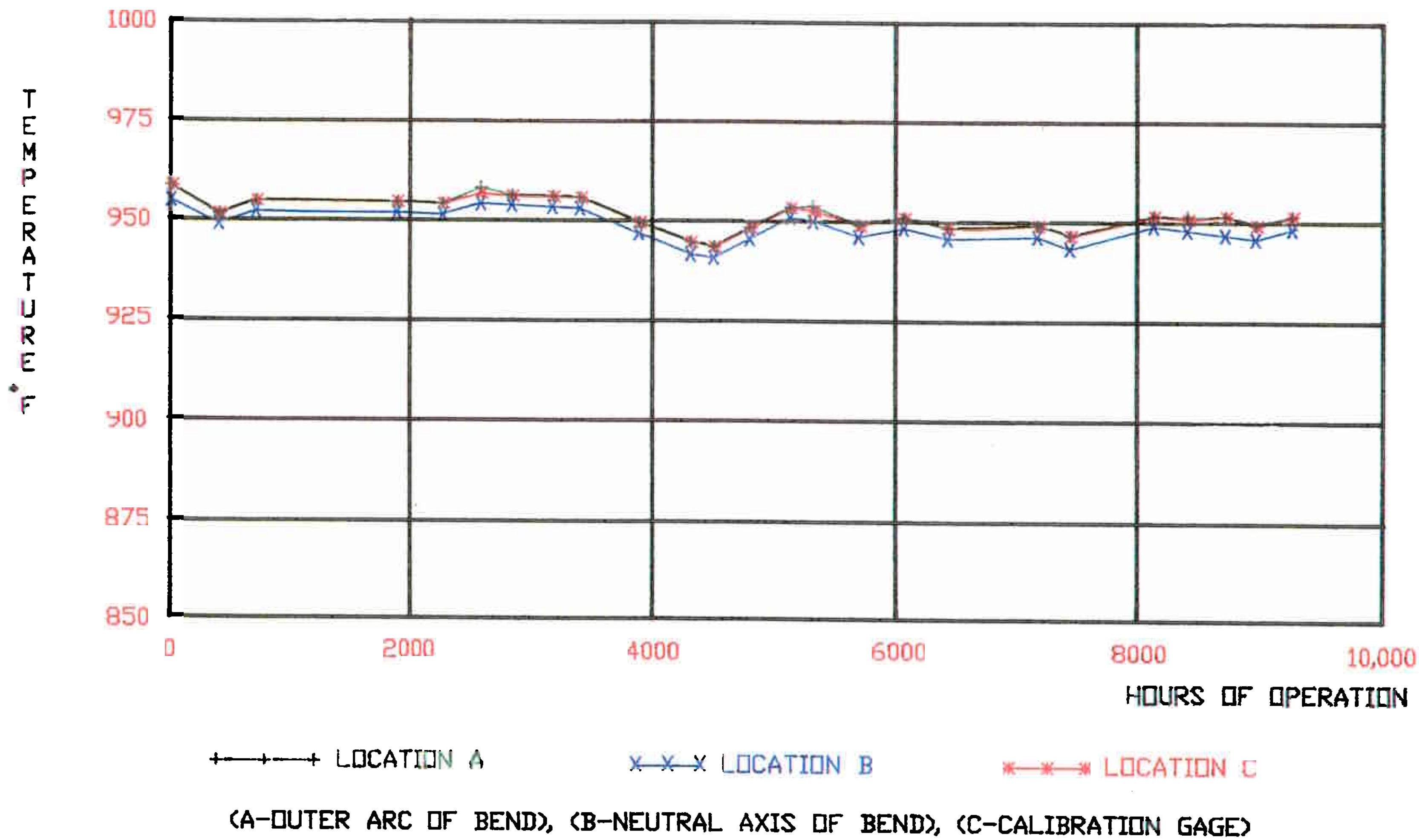

FIG. 2. TEMPERATURES OF PIPE AT LOCATION OF CREEP STRAIN MEASUREMENTS OF PIPE BEND SHOWN IN FIG. 1.

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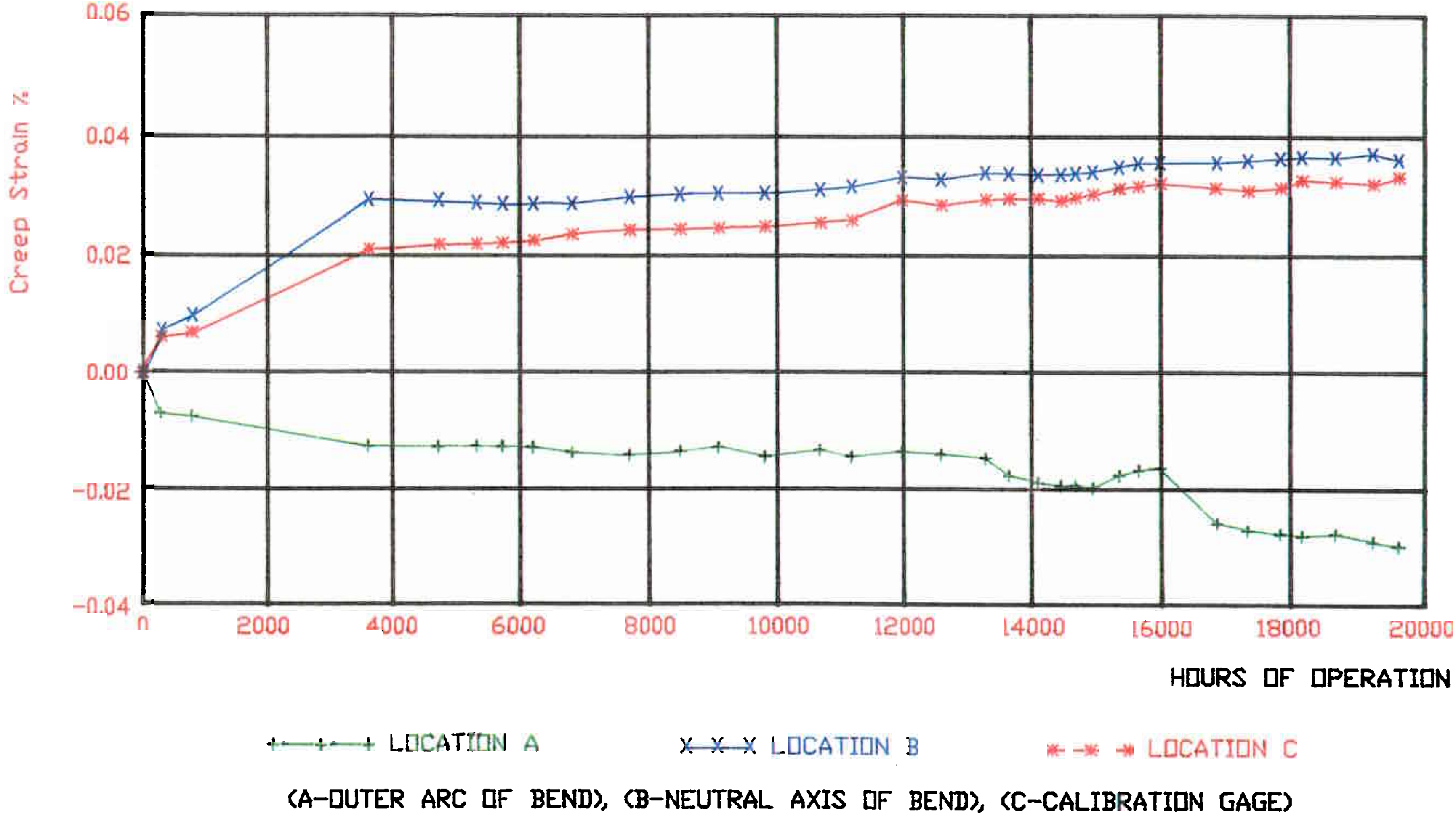

FIG. 3. CREEP STRAIN MEASUREMENTS OF PIPE BEND IN MAIN STEAM PIPING SYSTEM AFTER 195,000 HOURS OF OPERATION. THE PIPE MATERIAL IS 2 1/4Cr - 1Mo LOW ALLOY STEEL.

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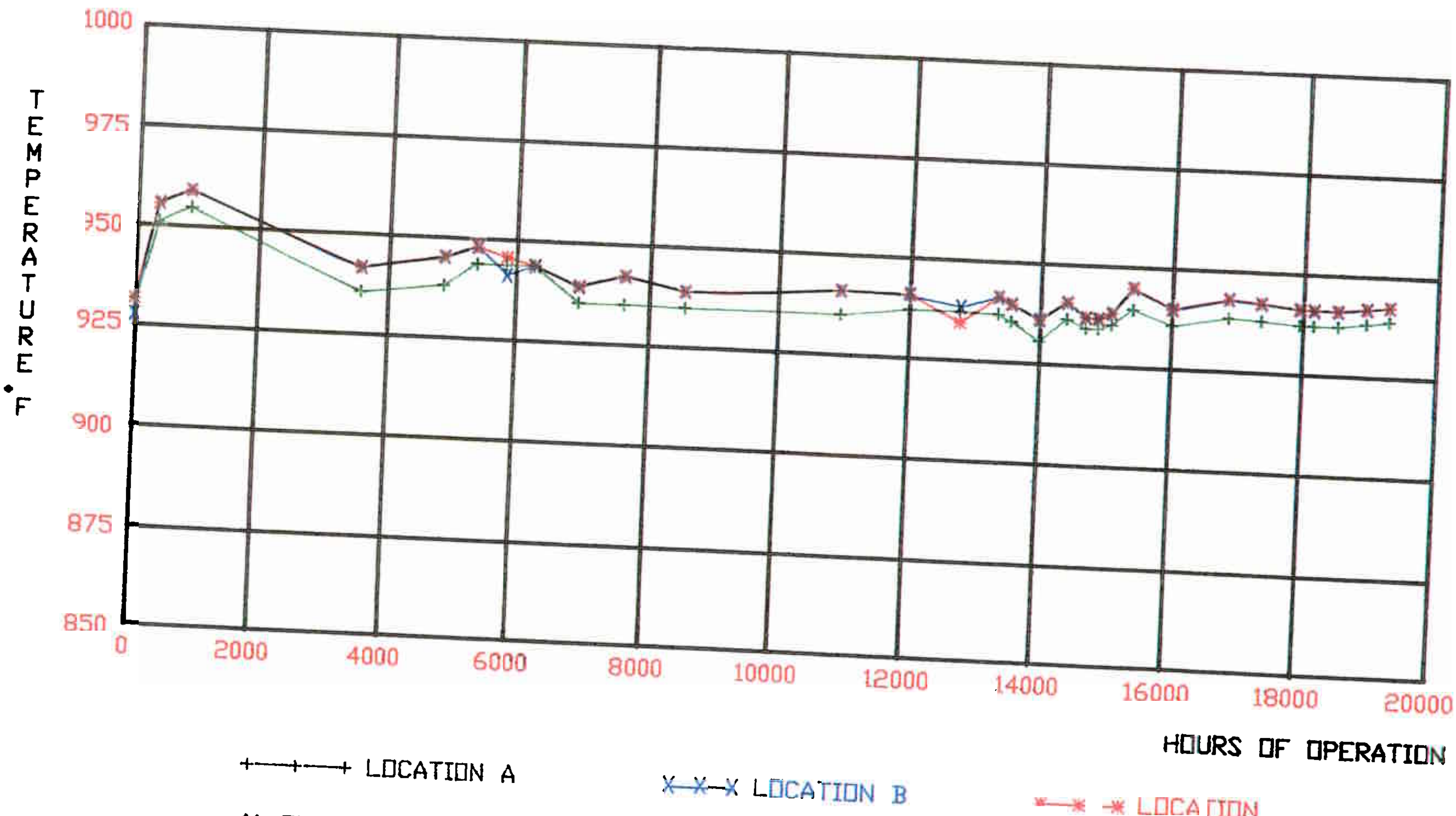

(A-OUTER ARC OF BEND), (B-NEUTRAL AXIS OF BEND), (C-CALIBRATION GAGE)

FIG. 4. TEMPERATURES OF PIPE AT LOCATION OF CREEP STRAIN MEASUREMENTS OF PIPE BEND IN FIG. 3.

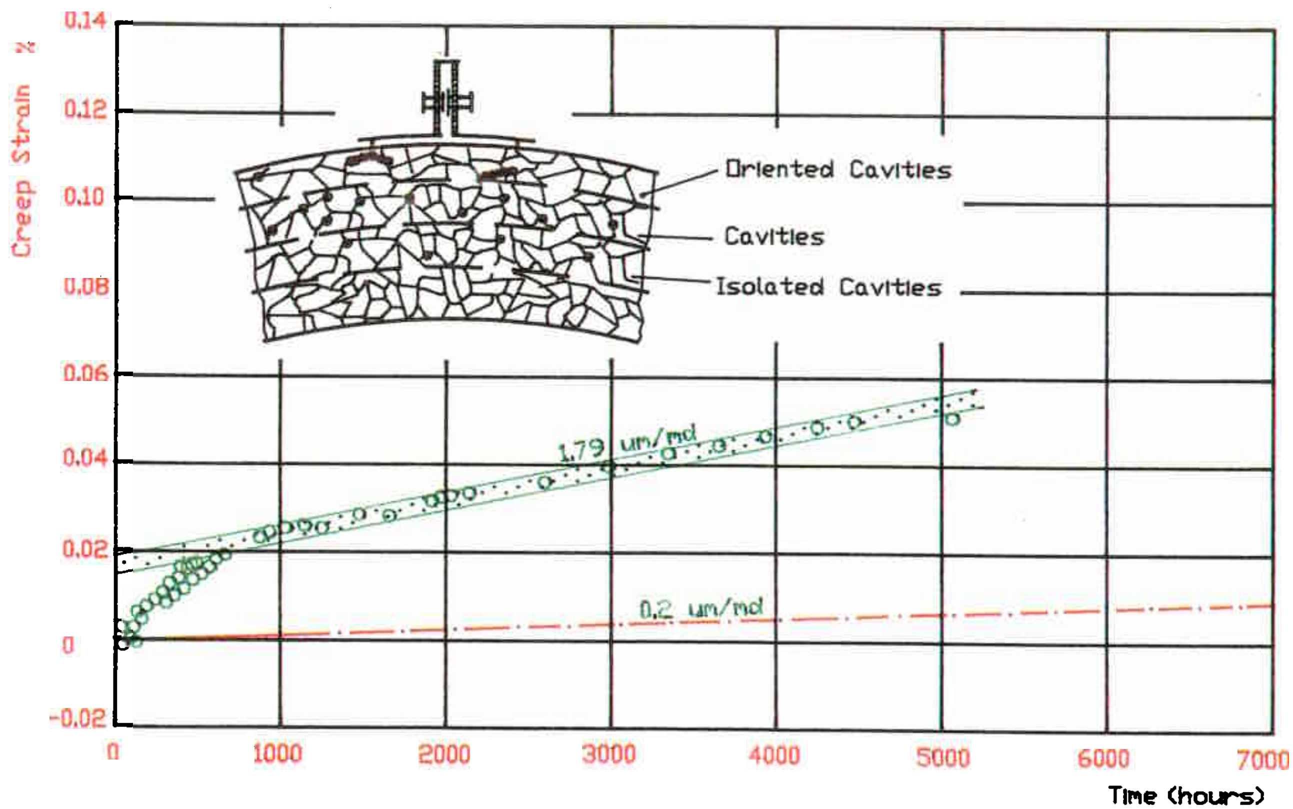

FIG. 5. RELATIONSHIP OF CREEP STRAIN AND CREEP VOID FORMATION AND VOID LINKAGE IN OUTER ARC OF PIPE BEND OF 1 1/4Cr - 1/2Mo LOW ALLOY STEEL. STRAIN GAGES WERE ATTACHED AFTER 243,000 HOURS OF SERVICE. ESTIMATED TOTAL STRAIN = 1.85 %.

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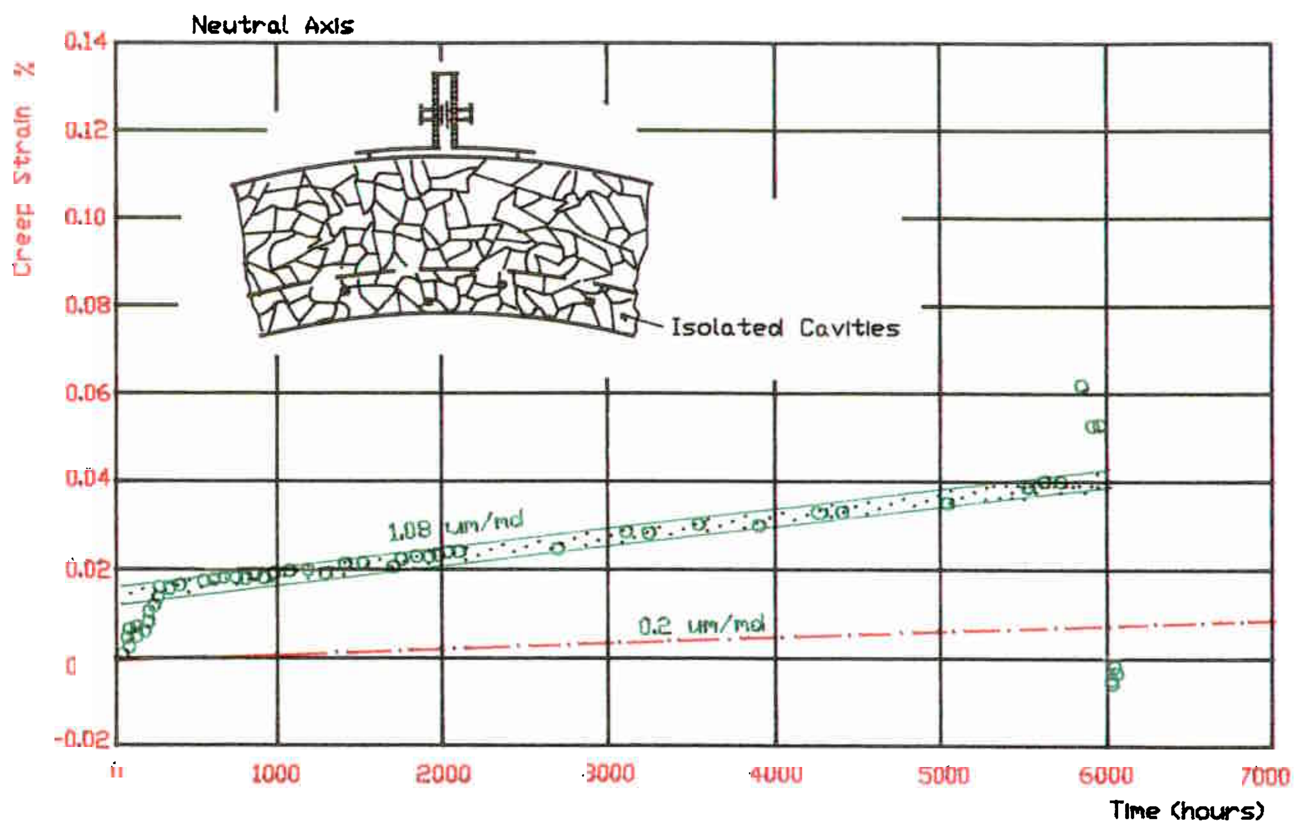

FIG. 6. RELATIONSHIP OF CREEP STRAIN AND CREEP VOID FORMATION ALONG NEUTRAL AXIS OF PIPE BEND OF 1 1/4Cr - 1/2Mo LOW ALLOY STEEL. STRAIN GAGES WERE ATTACHED AFTER 243,000 HOURS OF OPERATION. ESTIMATED TOTAL STRAIN = 1.12 %.

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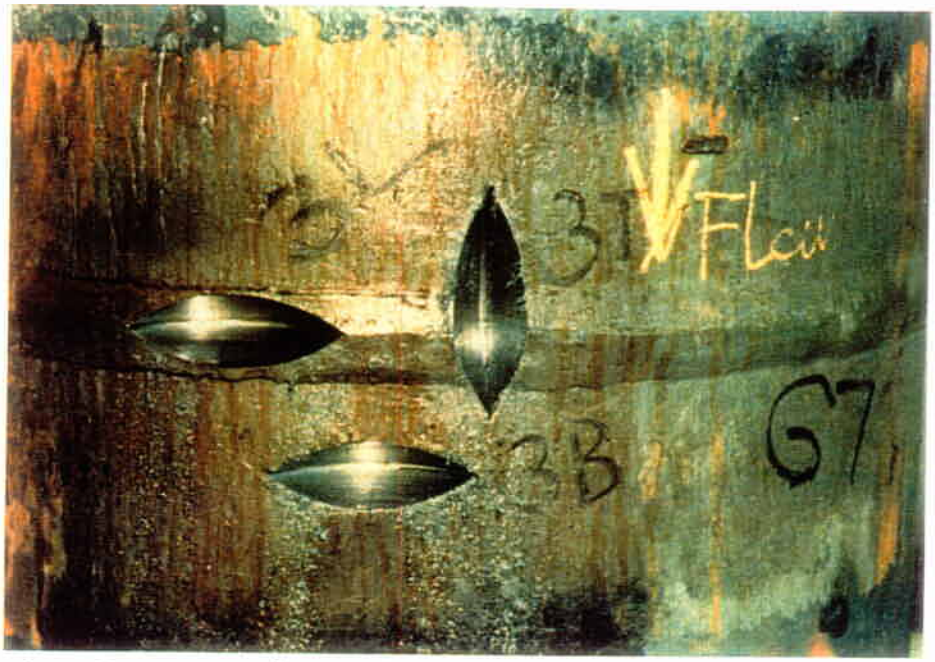

Fig. 7. Locations where samples were removed from a girth weld for creep testing.

Fig. 8. Locations where samples were removed from a seam weld in hot reheat pipe section for creep testing.

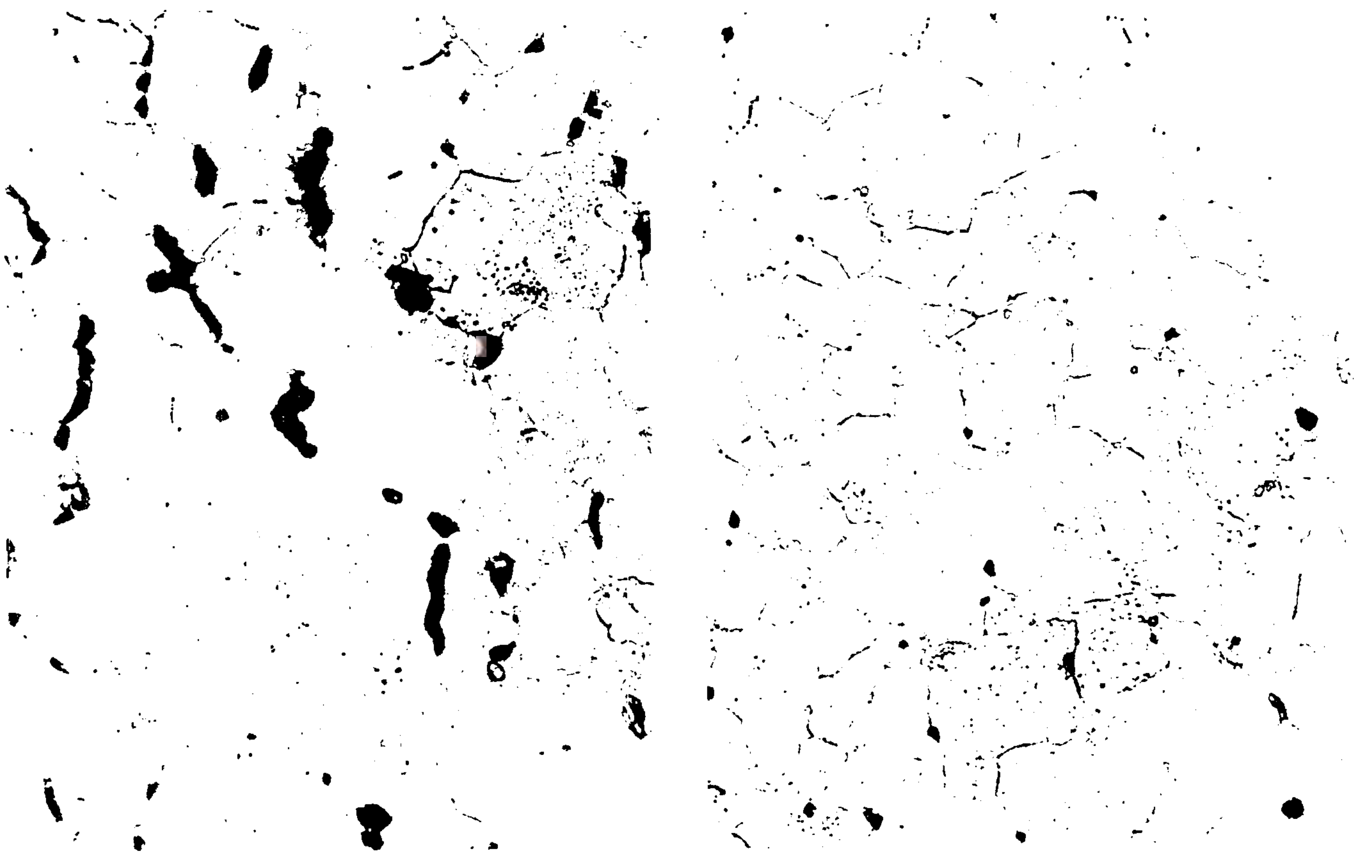

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Fig. 9. Microstructures examined for evidence of surface and subsurface void formation and void linkage.

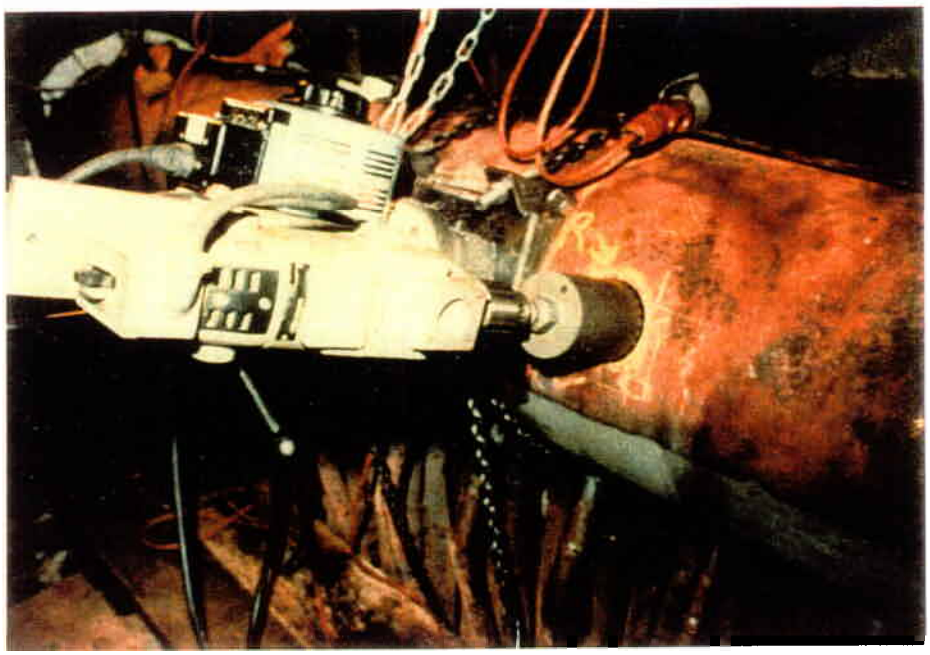


Fig. 10. Plug sample removed from superheater outlet header for creep testing.

Fig. 11. Typical installation of capacitive strain gages on surface of main steam pipe.

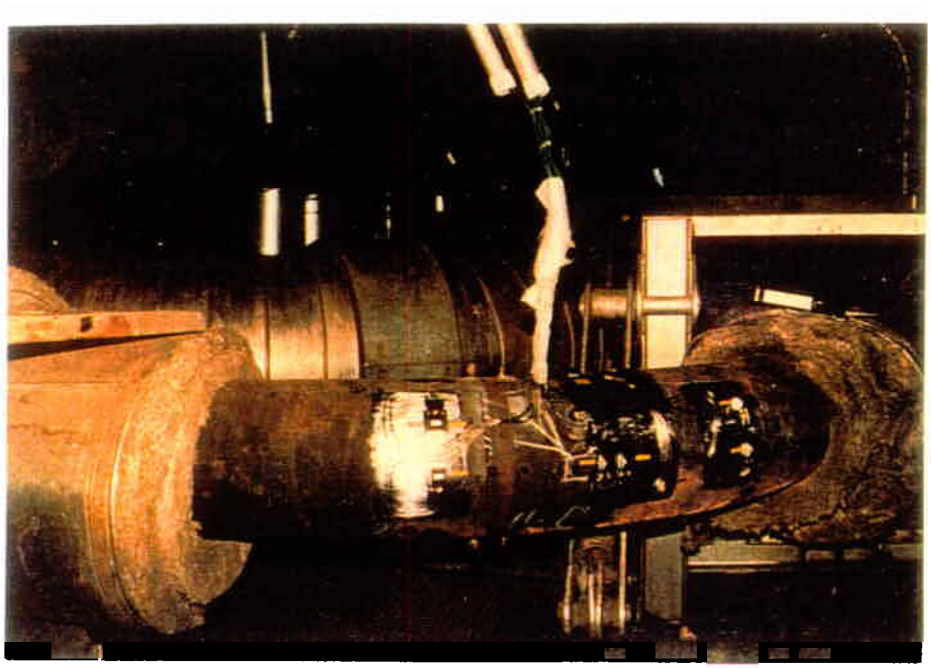


Fig. 12. Capcitive strain gages installed on the outer arc and neutral axis of main steam pipe bend.

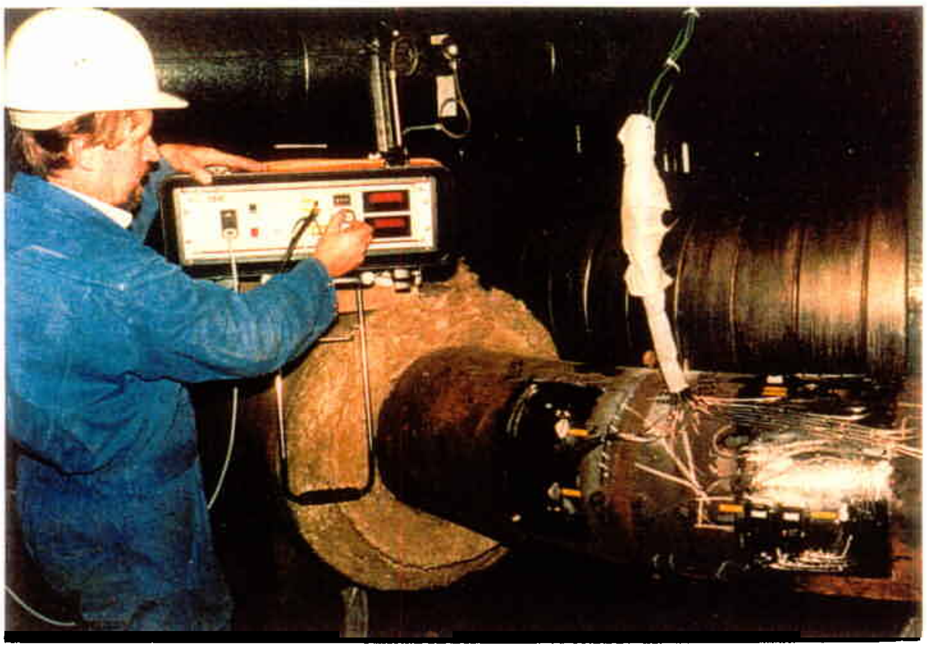


Fig. 13. Calibration and baseline data recorded prior to reinsulation and piping system start-up.

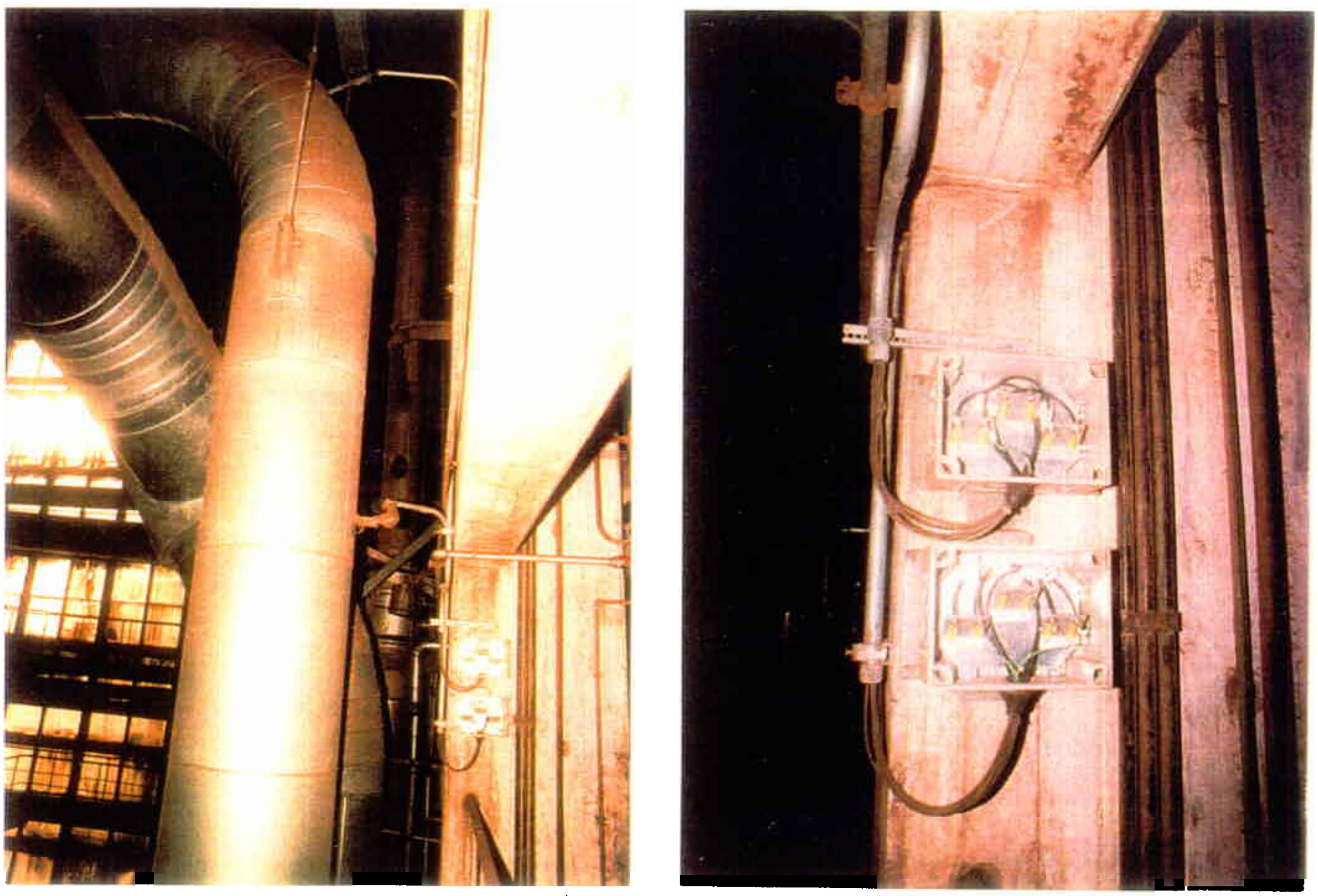
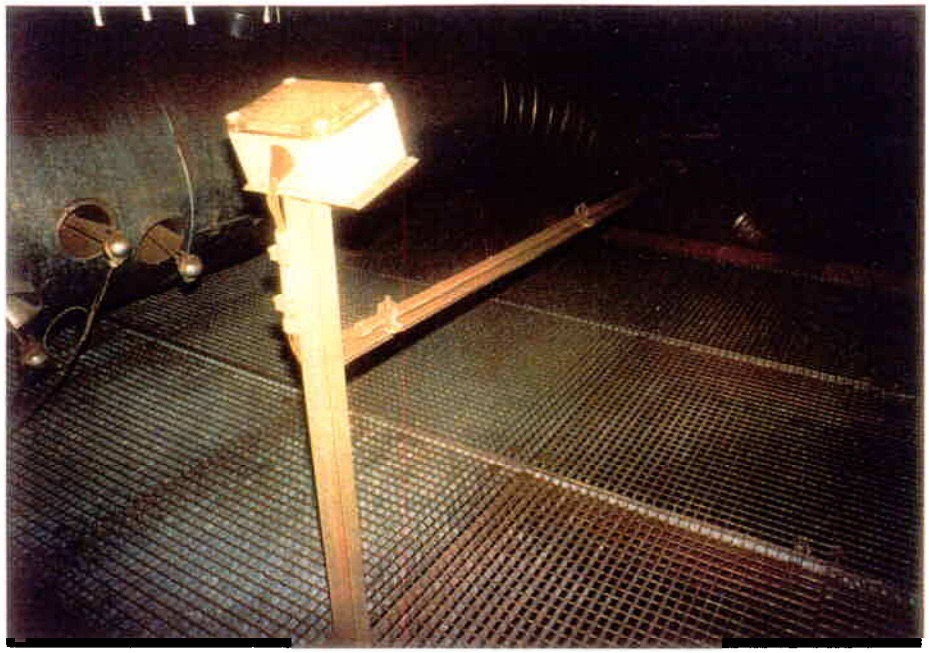


Fig. 14. Terminal boxes attached to the building wall.



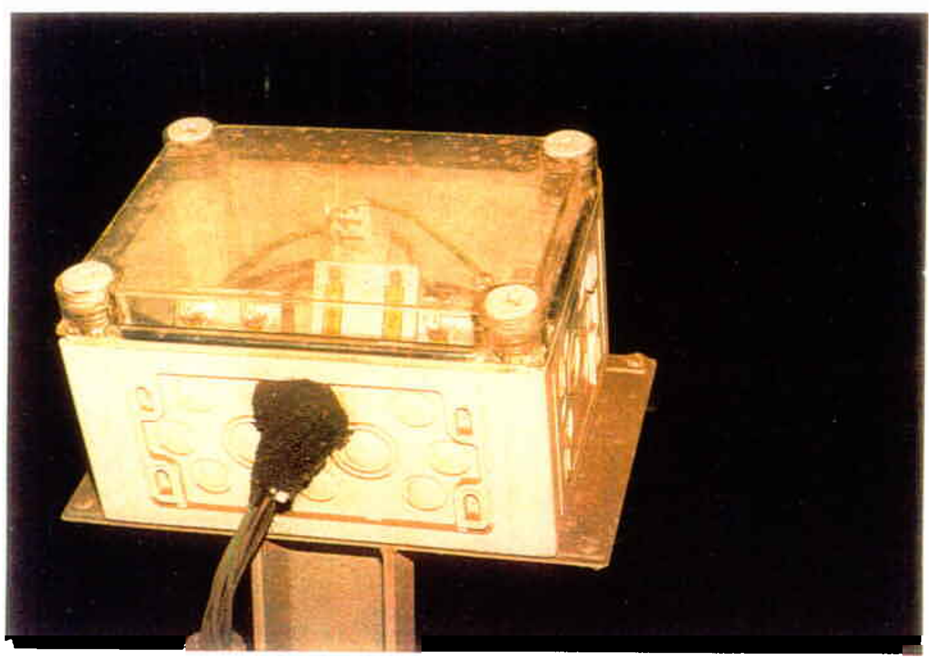


Fig. 15. Terminal box attached to special mounting bracket.